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Article Sub-Title		
Article CopyRight	Springer Science+Business Media, LLC (This will be the copyright line in the final PDF)	
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Schedule	Received Revised Accepted

Abstract	This paper examines financial integration among stock markets in the Eurozone using the prices from each stock index. Monthly time series are constructed for four major stock indices for the period between 1998 and 2016. A fractional cointegrated vector autoregressive model is estimated at an international level. Our results show that there is a perfect and complete Euro financial integration. Considering the possible existence of structural breaks, this paper also examines the fractional cointegration within each regime, showing that Euro financial integration is very robust. However, in the financial and sovereign debt crisis regime, IBEX 35 appears to be the weak link in Euro financial integration, unless Euro financial integration recovers when this period ends.

Keywords (separated by '-')	Fractional cointegration - Eurozone - Financial integration - Financial market cointegration
JEL Classification (separated by '-')	C32 - F41 - G15
Footnote Information	

Empirica
DOI 10.1007/s10663-017-9386-2

ORIGINAL PAPER

How did the Sovereign debt crisis affect the Euro financial integration? A fractional cointegration approach

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Abstract This paper examines financial integration among stock markets in the Eurozone using the prices from each stock index. Monthly time series are constructed for four major stock indices for the period between 1998 and 2016. A fractional cointegrated vector autoregressive model is estimated at an international level. Our results show that there is a perfect and complete Euro financial integration. Considering the possible existence of structural breaks, this paper also examines the fractional cointegration within each regime, showing that Euro financial integration is very robust. However, in the financial and sovereign debt crisis regime, IBEX 35 appears to be the weak link in Euro financial integration, unless Euro financial integration recovers when this period ends.

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Journal : **Small-ext 10663**	Dispatch : **10-8-2017**	Pages : **22**
Article No. : **9386**	□ LE	□ TYPESET
MS Code : **EMPI-D-17-00002**	☑ CP	☑ DISK

1 Introduction

The convergence of international markets has resulted from multiple confluences of economic, technological and political factors that have allowed national and international regulations to increasingly align with economic forces and globalization processes. The formation of the Euro was an effort to enhance synergies of member countries, creating highly favourable conditions in which capital markets could develop important similarities between them (Salgado et al. 2015).

Relationships between stock markets have been widely studied from different perspectives. Using techniques such as EMH (Kim et al. 2009), CAPM (Heimonen 2010) and/or GARCH (Illueca and Lafuente 2002), conclusions about relationships, convergence or co-movements among markets have been reached. Furthermore, several techniques have been used to apply time series data (see Brooks 2014) to integration and cointegration among different global economic regions, mainly the USA-EU (see Caporale et al. 2015, among others), and intraregional markets, such as members of the EMU (Da Fonseca 2013).

The aim of this paper is to study financial integration among the four major stock markets in the Eurozone (Germany, France, Spain and Italy) for the period of January 1998 to September 2016 from an econometric perspective.[1] This paper presents a novel approach to the integration of stock markets, filling a gap in the literature with regard to time series analysis of market cointegration. In this sense, our paper contributes to previous literature on the analysis of the integration of stock markets from a fractional cointegration vector autoregressive perspective. Although fractional cointegration had been used in previous studies, the approach proposed by Johansen (2008a) and Johansen and Nielsen (2012) is novel to the literature. This model, which is extended to allow for deterministic trends, has advantages when estimating a system of fractional time series variables that are potentially cointegrated. Additionally, the flexibility of the model allows one to determine the number of equilibrium relations via statistical tests and jointly estimate the adjustment coefficients and cointegrating relations while accounting for short-run dynamics. We use data with a monthly frequency to estimate the model, then perform statistical tests of cointegration, exclusion and weak exogeneity. We then apply the Bai and Perron (2003)test for structural breaks and use the FCVAR model to examine each break detected.

The remainder of the paper is organized as follows. Section 2 provides a review of the literature, focusing initially on the techniques used to study stock markets and subsequently on the application of the integration and cointegration test in different economic regions. Section 3 presents the methodology applied. Section 4 discusses the empirical results, and conclusions are presented in Sect. 5.

[1] The stock markets studied include the German stock market, the behavior of which is reflected in the DAX index; the French stock market, reflected in the CAC 40 index; the Italian stock market, as indicated by the FTSE MIB index; and the Spanish stock market, as shown by the IBEX 35 index. The choice of a stock market is based on the size of the respective national economy and the capitalization of the stock markets, which are the major ones in the Eurozone.

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	MS Code : EMPI-D-17-00002	☑ CP	☑ DISK

2 Literature review

Some measure of market development is essential in making intertemporal comparisons. For this reason, the treatment of such variables can explain the relationship between markets in the same economic region or, conversely, whether markets in different regions exhibit similar behaviour. As a result of computerized trading systems, markets can operate simultaneously. This allows for the study of the integration of stock markets, whose interrelations had previously been studied in various ways, e.g., using financial techniques such as the Efficient Market Hypothesis (EMH) or the Capital Asset Pricing Model (CAPM), until econometric models such the unit root test, GARCH and cointegration tests became available. The EMH is based on return predictability, as seen in the past price history of a market (Fama 1970, 1991), combined with other techniques such as the unit root test (Kim et al. 2009) or the variance ratio test[2] (Huang 1995; Smith 2007).

In contrast to previous research that has sought to explain intra-market behaviour, new research exploring this link has emerged, using other techniques, such as the international Capital Asset Pricing Model (CAPM) (Sharpe 1964), which proposes that stock market returns are affected by interest rates movements. Thus, for an investor in international markets, excess returns are related to changes in exchange rates (Heimonen 2010). Moreover, Yang (2012) combined the CAPM and cointegration to explain how benchmark markets are integrated with the global market. Over the decades, researchers have found the study of integration to be a useful approach to the study of the behaviour of inter-markets.[3] To illustrate the concept of integration, we note that markets are integrated when investors can pass from one market to another at no extra cost and when possibilities for arbitrage ensure the equivalence of share prices in both markets (Jawadi and Arouri 2008). Early papers, seeking to demonstrate integrated markets, proposed techniques such as correlation tests to explain short-run portfolio diversification (Solnik 1974; Longin and Solnik 1995).

Nevertheless, in reviewing the existing literature, we found that most studies examined the integration of world stock markets only in a linear framework, using correlation tests as a tool of data analysis. Examples include Hamao et al. (1990) and (Markellos and Siriopoulos 1997). Hence, some researchers have confirmed the existence of relationships using the GARCH model to explore co-movements[4] among stock markets (Illueca and Lafuente (2002); Chouliaras et al. (2012); Da Fonseca (2013) and Lee and Mercurelli (2014)), assuming that positive and negative error terms have symmetric effects on volatility. In more recent times, some researchers have utilized a variance of cointegration technique, specifically, fractional cointegration. For example, Caporale et al. (2015) use this technique to

[2] Lo and Mackinlay (1988) examined the predictability of time series by comparing the variances of differences in the data calculated over different intervals.

[3] Henceforth, we consider the relationships denoted by inter-markets to be the relationships among markets.

[4] Forbes and Rigobon (2002) explained co-movement as contagion, i.e., as a significant increase in cross-market linkages after a shock to one country or group of countries.

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analyse linkages among US and European markets. They indicate that shocks that affect long-run relationships vanish at a very slow rate. Gagnon et al. (2016) also use this method to study the cointegration of risk-neutral moments of five major stock markets in Europe, showing that there is strong financial integration and concluding that such integration is partial when anticipations are considered.

2.1 Empirical cointegration approach for the stock market analysis

This section explores the targets of the cointegration analysis that has been applied to stock markets. Research into integration and cointegration has employed several techniques, such as unit root tests of Dickey and Fuller (1979, 1981), used to establish the order of integration. Although in these papers, the authors provide one of the most influential works in the field of unit root tests, the test has low power because long memory processes cannot be explained by this test (Caporale et al. 2015). Subsequently, the cointegration of the variables was analysed, using the multivariate cointegration test of Johansen (1988, 1991), which enables testing of the cross-country market efficiency hypothesis. The Johansen cointegration test is used to show common stochastic trends across stock markets, and for this purpose, this test affords more robust results than other cointegration tests when there are more than two variables (Gonzalo 1994). According to this idea, since the seminal paper of Kasa (1992), who studied the financial integration of five developed markets, applying common stochastic trends in these series. As a consequence, this methodology has led to numerous studies that find long-run co-movements between international stock markets, using univariate or multivariate cointegration models—for instance, Kenourgios et al. (2009), Yang et al. (2003) and Tian (2007).

Stock market analysis has been applied to different regions of the world, but most relevant studies have focused on the USA and Europe and their relations. Many strands of research, using cointegration tests, have obtained mixed results regarding market relationships. One strand focuses on US stock markets; Gil-Alana et al. (2013) observed very similar patterns in US stock markets for daily prices during the 1971–2007 period. Granger and Hyung (2004) and Mikosch and Starica (2000), using different techniques, explained the cointegration through structural breaks, showing long memory dependence. Conversely, Alvarez-Ramirez et al. (2008) demonstrated a shift in long-term behaviour—that is, a random walk. Additionally, empirical studies of relationships among international stock markets have focused on the United States. For example, Francis and Leachman (1998) and Richards (1995) both examined the existence of cointegration relationships between the developed European and U.S. markets. The first demonstrated long-run equilibrium among markets, whereas the second showed that national return indices are not cointegrated. Caporale et al. (2015) used fractional cointegration to find linkages between US and European stock markets, contrasting different recovery paths due to monetary policy pursued in the two economies. Studies have also shown relations between US or European markets and Asian markets. For example, Wong et al. (2004) utilized fractional cointegration, reporting linkages between India, the USA, the UK and Japan. While this approach is extensively used in the literature, another strand in the literature focuses on stock markets within Europe. Taylor and Tonks

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(1989) and Corhay, Rad and Urbain (1993) found strong evidence for cointegration among several major European stock markets in the late 1970s and 1980s. In an international context, Bessler and Yang (2003) sought to demonstrate interdependence among nine major stock markets, finding that they are not fully integrated, and Darrat and Zhong (2005) studied cointegration between NAFTA countries, showing stable long-run linkage between the three stock markets. In addition, Kasa (1992) noted a common stochastic trend in the equity index prices of five developed countries, while Dickinson (2000) found that a cointegrating relationship between the major European stock markets exists and may be partly driven by the long-run relationships of macroeconomic fundamentals among these countries, possibly through indirect channels of international interaction.

Overall, a growing literature is emerging, one that seeks to explain the process of market integration due the convergence, using cointegration and taking into account endogeneity issues (Chouliaras et al. 2012; Syriopoulos 2007; Bley 2009; Mylonidis and Kollias 2010; Lee and Mercurelli 2014) and/or structural breaks (Kim et al. 2005; Demian 2011; Karmann and Ludwing 2014). However, Da Fonseca (2013), using a VAR model, demonstrated that the major stock markets in the Euro area were not perfectly integrated during the first decade of the EMU. In sum, this technique provides a mode of demonstrating different ways of explaining market integration in different contexts. Caporale et al. (2015) recently showed that cointegration has also been used to determine whether there are diversification benefits from investing in different stock markets.

If cointegration does not hold, markets are not linked in the long run, and therefore, it is possible to gain from diversification. For this reason, testing for cointegration and any changes over time in its degree is important. For example, Richards (1995) demonstrated a lack of cointegration among various stock markets and hence the existence of diversification benefits for investors. From a theoretical perspective, applying the fractional cointegration technique (FCVAR model), which is an expansion of the CVAR approach (see Johansen 1995), is adequate to provide more information about the cointegrating rank, the adjustments of the coefficients and long-run relationships among different variables—which in the present case are financial markets [see, Gagnon et al. (2016)].

3 Methodology

Our econometric strategy involves analysis of stock price data at monthly frequency. Once we have our model estimation, we perform statistical tests of cointegration, exclusion and weak exogeneity. We then apply the Bai and Perron (2003) test for structural breaks and use the FCVAR model to examine each break detected.[5]

[5] An alternative to our application is to take into account structural breaks, aiming to control the dynamics. As suggested by Johansen (2014), in practice, it is important to check the breaks in the dynamics. From this perspective, Hansen and Johansen (1999) proposed the theory of recursive estimation in the standard cointegration model.

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3.1 Fractional cointegration model: FCVAR methodology

Our objective is to study the interdependence of the major Euro stock markets. In this paper, the FCVAR model allows us to study the common long-run equilibrium relationship between market indices. The model is a generalization of Johansen's (1995) cointegrated vector autoregressive (CVAR) model to allow for fractional processes of order d that co-integrate to order d−b. This model has the advantage of being used for stationary and non-stationary time series. This model is presented in Johansen (2008a, b) and further developed in Johansen and Nielsen (2012) and Nielsen and Popiel (2016), and is gaining traction in finance (Bollerslev et al. 2013 and Gagnon et al. 2016).

To introduce the FCVAR model, we begin with the well-known, non-fractional, CVAR model. Being $Y_t = 1,\ldots,T$ a p-dimensional I (1) time series. So, the CVAR model is:

$$\Delta Y_t = \alpha\beta' Y_{t-1} + \sum_{i=1}^{k} \Gamma_i \Delta Y_{t-i} + \varepsilon t = \alpha\beta' L Y_t + \sum_{i=1}^{k} \Gamma_i \Delta L^i Y_t + \varepsilon_t \tag{1}$$

The fractional difference operator introducing persistence in the model is Δ and the fractional lag operator is Δ = (1 − L). Replacing lags operators in by their fractional counterparts Δ^b and Δ^b = (1 − L_b), we obtain:

$$\Delta^b Y_t = \alpha\beta' L_b Y_t + \sum_{i=1}^{k} \Gamma_i \Delta^b L_b^i Y_t + \varepsilon_t, \tag{2}$$

we apply to $Y_t = \Delta^{d-b} X_t$, such that:

$$\Delta^d X_t = \alpha\beta' L_b \Delta^{d-b} X_t + \sum_{i=1}^{k} \Gamma_i \Delta^d L_b^i X_t + \varepsilon_t. \tag{3}$$

As always, ε_t is p-dimensional independent and identically distributed with mean zero and covariance matrix Ω. The parameters α and β are $p \times r$ matrices, where $0 \le r \le p$. In matrix β the columns are the cointegrating relationships and $\beta' X_t$ are the stationary combinations, i.e., the long-run equilibrium. We follow the assumption derived from the seminal paper of Kasa (1992) about linearity in the relationship. However, on this linearity in our approach, once we are subject to this condition, seeks the study of changes in the behavior of the series through the analysis of structural breaks proposed by Bai and Perron (2003) as above mentioned, which allows us measure possible non-linearity in the time horizon of the relationship. The coefficients in α correspond the speed of adjustment unto equilibrium. Therefore, $\alpha\beta'$ is the adjustment long-run and Γ_i represents the short-run behavior of the variables.

Considering $d = b$ as an assumption of no persistence in the cointegration vectors and a constant mean term for the cointegrating relations, we reach an intermediate step before the final model. That is:

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$$\Delta^d X_t = \alpha(\beta' L_d X_t + \rho') + \sum_{i=1}^{k} \Gamma_i \Delta^d L_d^i X_t + \varepsilon_t. \tag{4}$$

We consider the simple model as:

$$\Delta^d (X_t - \mu) = L_d \alpha \beta' (X_t - \mu) + \sum_{i=1}^{k} \Gamma_i \Delta^d L_d^i (X_t - \mu) + \varepsilon_t, \tag{5}$$

where the variable μ is a level parameter that shifts each of the series by a constant in the way to avoid the bias related to the starting values in the sample (Johansen and Nielsen 2016). $\beta' \mu = -\rho'$ defines the mean stationary cointegrating relations.

Johansen and Nielsen (2012) show that the maximum likelihood estimators $(d, \alpha, \Gamma_i, \ldots, \Gamma_k)$ are asymptotically normal and the maximum likelihood estimator of (β, ρ) is asymptotically mixed normal.

For testing the hypotheses on the model parameters we use FCVAR model which is almost equal to CVAR (Johansen 1995). We test if a market is a part of a cointegrating relationship and is included in a long-run equilibrium. Hypotheses on β can be formulated:

$$\beta = H\varphi, \tag{6}$$

where H is a matrix of dimension $p \times s$ and contains the restrictions and φ is a matrix of free parameters with dimension $s \times r$. The degrees of freedom are given by $df = (p - s)r$. If $r > 1$, the degrees of freedom of the test is $df = \sum_{i=1}^{r} (p - r - s_i + 1)$ (Jones et al. 2014).

With the test of hypotheses α, we test the weak exogeneity as:

$$\alpha = A\psi, \tag{7}$$

where A is a matrix of dimension $p \times m$ and ψ is a $m \times r$ matrix of free parameters with $m \geq r$ (Jones et al. 2014). The degree of freedom of the test is given by $df = (p - m)r$. If a row of α is zero, the associated variable is weakly exogenous.

Note that matrix α and β are normalized separately in the same way for the CVAR model because the degrees of freedom are non-standard.

To sum up, by estimating the CFVAR model, we extract richer information from what was mentioned in previous sections. Importantly, by separately parameterizing the long-run and the short-run dynamics of the series, the model is able to accommodate empirically realistic I(d) long-memory and their fractional cointegration, while maintaining that the returns are $I(0)$ (Bollerslev et al. 2013).

4 Empirical analysis

Data description For our empirical analysis, we use a sample of closing stock market prices of the four major stock markets of the Eurozone, namely, Germany (DAX), France (CAC), Spain (IBEX) and Italy (FTSE MIB). The data are collected from Yahoo! Finance. Our series are monthly and run from January 1998 to

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November 2016 (amounting 227 observations). Our analysis begins after converting all series to natural logarithms.

In Table 1 and Fig. 1, we present descriptive statistics and the dynamics of our series. The descriptive statistics associated with the closing prices of each index, shown in Table 1, reveal that the FTSE MIB index has the highest volatility, while the CAC40 has the lowest, and IBEX and DAX have similar volatility coefficients. For its part, Fig. 1 presents the time series dynamics for all indices in terms of how the series move; a common trend emerges among the monthly closing prices of these indices.

Table 1 Descriptive statistics for the options data

	DAX	CAC 40	IBEX 35	FTSE MIB
Mean	6440.8	4283.2	9797.4	27,678.0
Median	6123.3	4229.4	9741.5	25,919.0
Min	2423.9	2618.5	5431.7	12,874.0
Max	11,966.0	6625.4	15,890.0	48,479.0
SD	2131.0	891.35	2071.5	9137.1

From 01/1998 to 11/2016

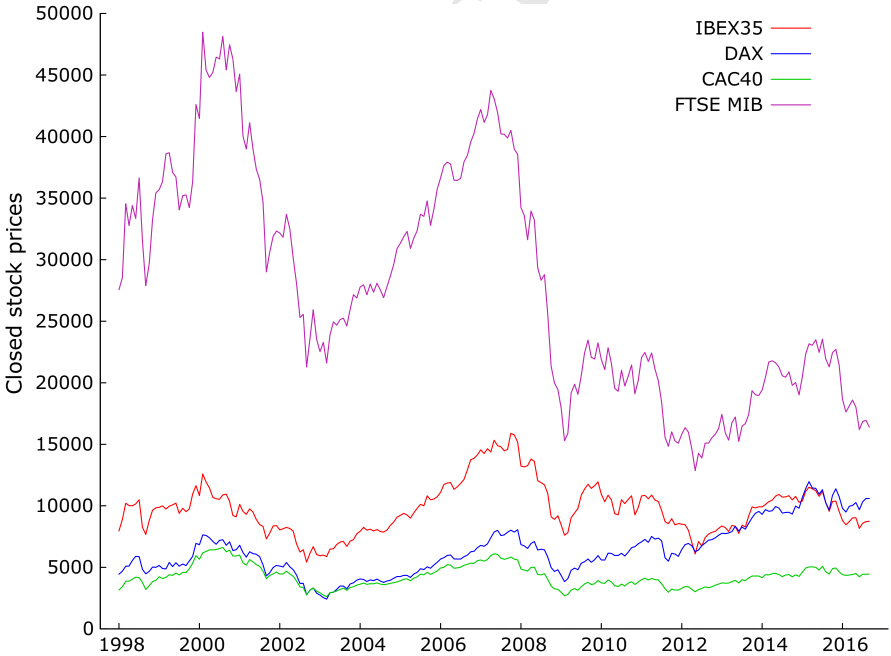

Fig. 1 Time series plot for used variables

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4.1 Testing for fractional cointegration

This section analyses the fractional cointegration of two paths: Univariate analysis is presented as an introduction to the second, multivariate analysis.

4.1.1 Univariate analysis

To determine whether the FCVAR model is appropriate to our data, we examine each of our series individually before conducting the multivariate analysis. In general, if both stationarity tests and unit root tests of a time series are rejected, that implies that the time series is likely a fractional time series. Therefore, before obtaining estimates of *d*, we perform augmented Dickey–Fuller (ADF) and Ng–Perron (2001) tests for unit roots on each of our individual series. The results are shown in Table 2. All tests reject stationarity, and tests of stock markets do no reject the presence of a unit root.

There are several procedures for estimating the fractional differencing parameter in semiparametric contexts. Although the semiparametric log-periodogram regression proposed by Geweke and Porter-Hudak (1983) is the most used, this method was modified and further developed by Robinson (1995) and has been analysed by Velasco (1999) and Phillips and Shimotsu (2002), among others. Next, we proceed to the estimation of the fractional parameter *d* for each univariate series, with results presented in Table 3. The first three columns are semiparametric log-periodogram

Table 2 Ng–Perron and Augmented Dickey–Fuller unit root tests for the stock markets

	Parameter	DAX	CAC	FTSE	IBEX
Ng–Perron	$\overline{MZ}_{\alpha}^{GLS}$	−7.079	−5.552	−7.458	−8.617
	$\overline{MZ}_{t}^{GLS}$	−1.854	−1.166	−1.195	−2.046
	$\overline{MSB}^{GLS}$	0.262	0.300	0.257	0.237
	$\overline{MPT}^{GLS}$	12.919	16.411	12.256	10.687
ADF	Statistic	−1.891	−2.313	−2.457	−2.236
Critical values (%)	Ng–Perron				ADF
	$\overline{MZ}_{\alpha}^{GLS}$	$\overline{MZ}_{t}^{GLS}$	$\overline{MSB}^{GLS}$	$\overline{MPT}^{GLS}$	$\tilde{t}_{\alpha}$
1	−23.800	−3.420	0.143	4.030	−3.999
5	−17.300	−2.910	0.168	5.480	−3.413
10	−14.200	−2.620	0.185	6.670	−3.139

The critical values for the Ng–Perron test are tabulated in Ng and Perron (2001). The *MAIC* information criteria is used to select the autoregressive truncation lag, *k*, as proposed in Perron and Ng (1996)

*** Rejects null hypothesis at 1% significance level

** Rejects null hypothesis at 5% significance level

* Rejects null hypothesis at 10% significance level

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Table 3 Univariate analysis

GPH estimates			
	m = $T^{0.4}$ *d*	m = $T^{0.5}$ *d*	m = $T^{0.6}$ *d*
DAX	1.051	1.056	1.165
	(0.223)	(0.108)	(0.132)
CAC 40	0.912	0.909	0.968
	(0.555)	(0.260)	(0.153)
IBEX 35	1.021	1.000	0.941
	(0.383)	(0.212)	(0.128)
FTSE MIB	1.189	1.050	1.170
	(0.169)	(0.168)	(0.195)

GPH denotes the Geweke and Porter-Hudak semiparametric log-periodogram regression estimator. Standard errors are given in parenthesis beneath estimates of *d*. The sample size is 227

regression estimates from Geweke and Porter-Hudak (1983), here labelled GPH, computed with bandwidths $m = T^{0.4}$, $m = T^{0.5}$, and $m = T^{0.6}$, respectively.[6]

4.1.2 Statistical and hypothesis test

First, we determine the number of stationary cointegrating relations, following the hypotheses of the rank test based on a series of LR tests: $H_0 : rank = r$, against the alternative: $H_1 : rank = p$ for $r = 0, 1,\ldots$. (See Johansen 1995).

The LR test statistics are provided in Johansen and Nielsen (2012), and the *P* values are available from MacKinnon and Nielsen (2014), based on their numerical distribution functions. The estimated rank is the first non-rejected value of the test, and when this rank is different from zero, we can also conclude that there exists a long-run equilibrium in the stock markets.

Once the rank cointegration test is established, we estimate the model parameters, using several hypothesis of interest[7] (Table 4). The first hypothesis is H_1^d, which examines whether fractional integration is more appropriate than traditional cointegration. The null hypothesis is $d = 1$, and its rejection implies that the FCVAR model is more suitable than a CVAR model. The remaining hypotheses can be divided into tests of a cointegrated relationship (β parameters) and tests for weak exogeneity of the variables (α parameters). The parameters in α and β are not identified without additional normalization restrictions; see Johansen (1995).

Our primary interest in the cointegrating vectors concerns whether our variables form a stationary long-run equilibrium. The hypotheses $H_1^\beta, H_2^\beta, H_3^\beta, H_4^\beta$ are used to test whether a given stock market is part of a cointegrating relationship and existing long-run equilibrium. If we reject these hypotheses, we can conclude that a long-run equilibrium relationship does not exist. The hypotheses $H_1^\alpha, H_2^\alpha, H_3^\alpha, H_4^\alpha$ are used to test whether each variable is individually weakly exogenous. If a row of α is zero,

[6] In order to test the presence of unit roots, the estimates were obtained using first-differenced data, because the original series might be above 0.5 and this test requires that the results are limited to the interval $-0.5 < d < 0.5$, then adding 1 to obtain the proper estimates of d.

[7] Hypothesis testing is explained in paragraph 3, Methodology.

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Table 4 Key for hypothesis test

$\boldsymbol{H_1^d}$	The fractional parameter, d, is equal to one
$\boldsymbol{H_1^\beta}$	FTSEMIB index does not enter the cointegrating relation(s)
$\boldsymbol{H_2^\beta}$	IBEX 35 index does not enter the cointegrating relation(s)
$\boldsymbol{H_3^\beta}$	CAC 40 index does not enter the cointegrating relation(s)
$\boldsymbol{H_4^\beta}$	DAX index does not enter the cointegrating relation(s)
$\boldsymbol{H_1^\alpha}$	FTSEMIB index is weakly exogenous
$\boldsymbol{H_2^\alpha}$	IBEX 35 index is weakly exogenous
$\boldsymbol{H_3^\alpha}$	CAC 40 index is weakly exogenous
$\boldsymbol{H_4^\alpha}$	DAX index is weakly exogenous

the variable does not respond to disequilibrium in the relationship. A rejection of the null hypothesis implies that a market index adjusts towards the long-run equilibrium after a shock.

4.1.3 Multivariate analysis

To complete our econometric strategy, we apply a multivariate analysis that allows us to estimate the possible relations among the variables used and test the different hypotheses. At the same time, the univariate analysis provides the value of the fractional integer. In this sense, Table 5 presents the estimation results for the FCVAR model applied to stock market prices. The null hypothesis of standard cointegration H_1^d is rejected with a P value of 0.000, suggesting that a fractional cointegration model is more appropriate. First, to stablish the lag selection, we apply BIC criteria (see the "Appendix", Table 11), selecting a lag length of one. To determine whether there is a long-run relationship among the stock markets selected, we test the cointegration rank before testing the hypotheses and find that the number of cointegrating vectors is three. We test hypotheses H_1^β, H_2^β, H_3^β, and H_4^β to verify that our variables are in the cointegrating relations, using the 10% level of significance to reject a given null hypothesis (Jones et al. 2014). The results presented for β confirm that we strongly reject the null hypothesis of the non-existence of a long-run equilibrium, with a P value of 0.000, except in the cases of the FTSE MIB and IBEX 35, which do not share a long-run relationship. Indeed, stock markets that are cointegrated have a long-run relationship, so long-run correlations are higher than short-run correlations. If n variables have p cointegrating relationships, they have $n - p$ common trends. When $n - p = 1$, as in the case studied, the individual stock markets are completely and perfectly integrated. Moreover, the test of weak exogeneity suggests that the selected stock markets are not weakly exogenous.[8]

[8] If a stock market is weakly exogenous, anticipations in this stock market do not adjust to shifts in anticipations for other markets.

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Table 5 Estimated result for FCVAR

Lags	1		
Coint. relation (β)	1	2	3
FTSE MIB	1.000	0	0
IBEX 35	0	1.000	0
CAC 40	0	0	1.000
DAX	0.380	1.143	−0.612
Adjustment matrix (α)			
FTSE MIB	−0.169	0.008	0.014
IBEX 35	−0.129	−0.002	0.091
CAC 40	−0.082	−0.025	−0.046
DAX	−0.323	0.073	0.308

Hypothesis test	df	LR statistics	*P* value
H_1^d	1	25.422	0.000
H_1^β	3	4.798	0.187
H_2^β	3	3.719	0.237
H_3^β	3	27.186	0.000
H_4^β	3	97.504	0.000
H_1^α	3	17.904	0.000
H_2^α	3	31.168	0.000
H_3^α	3	9.730	0.021
H_4^α	3	30.797	0.000

The top part of the table indicates the optimal number of lags representing the short run dynamics and the estimations of β and α as well as their associated standard error in parenthesis. The bottom part of the table reports the *P* values for the test of exclusion and weak-exogeneity tested in the Hypothesis test. Following Jones et al. (2014), the significance level is set to 10% for exclusion and weak-exogeneity tests. The sample size is 227

4.2 Testing the fractional cointegration by structural breaks

We consider the possibility that the existence of structural breaks would provide a better empirical description of the European market integration. We now apply the test for structural breaks proposed by Bai and Perron (2003) with a 15% trimming, which limits the maximum number of breaks allowed under the alternative hypothesis to 3. Among the breaks identified, the first regime (1998:01 until 2001:04) is in the way to the introduction of the single currency thus the markets were regulating to the new financial context. The second regime (2001:05–2007:06) would correspond to the economic growth and expansion period of the countries of the stock markets selected. In the third regime (2007:07 until 2012:04), according to the European Area Business Cycle Dating Committee, there was the financial crisis and the sovereign debt crises. Finally, the fourth regime (2012:05–2016:11) would be the end of the sovereign crisis until today. Tables 6, 7, 8, 9 and 10 shows the results for each regime.

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Table 6 Bai−Perron tests of multiple structural changes in the relationship between the European stock markets

Statistics						
UDmax	*WDmax*	$SupF_t(1)$	$SupF_t(2)$	$SupF_t(3)$	$SupF_t(4)$	$SupF_t(5)$
256.711***	493.187***	125.278***	246.153***	221.508***	214.213***	256.711***
$SupF_t(2/1)$	$SupF_t(3/2)$	$SupF_t(4/3)$	$SupF_t(5/4)$			
231.393***	42.498***	44.156*	13.411			

Break dates estimates		
T_1	2001:4	[2000:03–2001:11]
T_2	2007:6	[2007:05–2007:10]
T_3	2012:4	[2012:01–2012:05]

*, **, and *** denote significance at the 10, 5 and 1% levels, respectively. The critical values are taken from Bai and Perron (1998), Tables 1 and 2; and from Bai and Perron (2003), Tables 1 and 2. The number of breaks has been determined according to the sequential procedure of Bai and Perron (1998), at the 1% size for the sequential test. 90% confidence intervals for T_1 in square brackets

Table 7 Estimated result for FCVAR (Regime 1)

Lags	1		
Coint. relation (β)	1	2	3
FTSE MIB	1.000	0	0
IBEX 35	0	1.000	0
CAC 40	0	0	1.000
DAX	−1.497	−0.234	−1.609
Hypothesis test	df	LR statistics	*P* value
$\mathbf{H}_1^{\mathbf{d}}$	1	42.259	0.000
$\mathbf{H}_1^{\beta}$	3	17.304	0.001
$\mathbf{H}_2^{\beta}$	3	9.679	0.022
$\mathbf{H}_3^{\beta}$	3	13.822	0.003
$\mathbf{H}_4^{\beta}$	3	10.378	0.016
$\mathbf{H}_1^{\alpha}$	3	9.837	0.020
$\mathbf{H}_2^{\alpha}$	3	6.058	0.109
$\mathbf{H}_3^{\alpha}$	3	4.582	0.205
$\mathbf{H}_4^{\alpha}$	3	7.626	0.054

The top part of the table indicates the optimal number of lags representing the short run dynamics and the estimations of β as well as their associated standard error in parenthesis. The bottom part of the table reports the *P* values for the test of exclusion and weak-exogeneity tested in the Hypothesis test. Following Jones et al. (2014), the significance level is set to 10% for exclusion and weak-exogeneity tests. The sample size is 41

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Table 8 Estimated result for FCVAR (Regime 2)

Lags	1		
Coint. relation (β)	1	2	3
FTSE MIB	1.000	0	0
IBEX 35	0	1	0
CAC 40	0	0	1
DAX	2.263	−1.758	1.234
Hypothesis test	df	LR statistics	*P* value
H_1^d	1	29.503	0.000
H_1^β	3	15.874	0.001
H_2^β	3	20.799	0.000
H_3^β	3	22.958	0.000
H_4^β	3	52.133	0.000
H_1^α	3	39.118	0.000
H_2^α	3	17.714	0.001
H_3^α	3	36.883	0.000
H_4^α	3	38.889	0.000

The top part of the table indicates the optimal number of lags representing the short run dynamics and the estimations of β as well as their associated standard error in parenthesis. The bottom part of the table reports the *P* values for the test of exclusion and weak-exogeneity tested in the Hypothesis test. Following Jones et al. (2014), the significance level is set to 10% for exclusion and weak-exogeneity tests. The sample size is 74

Once the structural breaks are defined, we proceed to use the FCVAR model to test each regime for cointegration and weak exogeneity. As can be seen in Table 7, the *P* value indicates that the null hypothesis of standard cointegration is rejected, suggesting that a fractional cointegration model is more appropriate. Applying the rank test (which is at most three), the number of cointegrating vectors is three; in other words, DAX, CAC 40, IBEX 35 and FTSE MIB are fully integrated. In view of the Hypothesis test, the results confirm a long-run equilibrium relationship among these variables. Based on the weak-exogeneity test, we accept the null hypothesis, with the IBEX 35 index and the CAC 40 index having *P* values of 0.109 and 0.205, respectively. Indeed, anticipations in these stock markets do not adjust to shifts that occur in the long-run relationship. The empirical results suggest that some linkage has existed over time, i.e., there is strong integration among the selected stock indices.

Turning to the second regime, Table 8 shows the results of the FCVAR model. It is observed that the null hypothesis of standard cointegration is strongly rejected. The behaviours of the cointegrating vectors match the results of the model applied to the original time series; we choose one lag to test the rank of the cointegrating vectors, finding three. Testing the β hypotheses, we determine that the null hypothesis of the non-existence of a long-run equilibrium is rejected in all cases, and we also reject the hypothesis of weak exogeneity. In sum, in this regime, the

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Table 9 Estimated result for FCVAR (Regime 3)

Lags		1		
Coint. relation (β)		1		2
FTSE MIB		1.000		0
IBEX 35		0		1.000
CAC 40		−1.842		−1.963
DAX		0.719		−0.146
Hypothesis test	df		LR statistics	*P* value
H_1^d	1		21.353	0.000
H_1^β	3		8.673	0.013
H_2^β	3		1.255	0.534
H_3^β	3		7.738	0.021
H_4^β	3		6.762	0.024
H_1^α	3		31.754	0.000
H_2^α	3		15.369	0.000
H_3^α	3		32.219	0.000
H_4^α	3		15.353	0.000

The top part of the table indicates the optimal number of lags representing the short run dynamics and the estimations of β as well as their associated standard error in parenthesis. The bottom part of the table reports the *P* values for the test of exclusion and weak-exogeneity tested in the Hypothesis test. Following Jones et al. (2014), the significance level is set to 10% for exclusion and weak-exogeneity tests. The sample size is 58

cointegrating vectors exhibit the same behaviour as in the original sample, implying that the stock indices are fully and perfectly integrated.

For the third regime (Table 9), which corresponds to the financial and European sovereign debt crisis period, we also strongly reject the null hypothesis of standard cointegration, with a *P* value of 0.000. Additionally, using the rank test, we find that there are two cointegrating vectors. Therefore, following Kasa (1992), the market integration is neither complete nor perfect. An explanation of this result is that this was a convulsive and uncertain period, and as we can see, the IBEX 35 index does not belong to the long-run relationship, perhaps owing to the observed integration weakness. Thus, the weak-exogeneity test shows that all markets adjust to shifts in anticipation of other markets. With respect to the IBEX 35 index, we appreciate that unless this market is not in the long-run relation, it is affected by such a relationship.

To complete our review of the regimes, the application of the FCVAR model to the fourth regime is shown in Table 10. First, as we have done previously, we test the hypothesis of standard cointegration, which is strongly rejected, with a *P* value of 0.000. Then, we test the rank of the cointegrating vector, finding three, which means that once the sovereign debt crisis ended, Euro market integration again became complete. In the case of the weak-exogeneity test, we observe that in none of the cases of the selected markets is the null hypothesis rejected, which means that

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Table 10 Estimated result for FCVAR (Regime 4)

Lags	1		
Coint. relation (β)	1	2	3
FTSE MIB	1.000	0	0
IBEX 35	0	1.000	0
CAC 40	0	0	1.000
DAX	0.014	0.129	−0.694
Hypothesis test	df	LR statistics	*P* value
H_1^d	1	34.563	0.000
H_1^β	3	14.667	0.002
H_2^β	3	22.645	0.000
H_3^β	3	7.039	0.071
H_4^β	3	8.971	0.030
H_1^α	3	27.253	0.000
H_2^α	3	26.205	0.000
H_3^α	3	24.059	0.000
H_4^α	3	16.717	0.001

The top part of the table indicates the optimal number of lags representing the short run dynamics and the estimations of β as well as their associated standard error in parenthesis. The bottom part of the table reports the *P* values for the test of exclusion and weak-exogeneity tested in the Hypothesis test. Following Jones et al. (2014), the significance level is set to 10% for exclusion and weak-exogeneity tests. The sample size is 54

anticipations in these stock markets do not adjust to shifts in the long-run relationship. The results obtained are similar to those for regime 2.

5 Conclusion

In this paper, we have studied European stock market cointegration, using a fractionally cointegrated vector autoregressive (FCVAR) model applied to the closing prices of the major four stock market indices in the Eurozone. Despite controversy in the existing literature regarding treatment of this issue, the fractional cointegration model avoids most of the problems raised in the literature. Additionally, this model allows us to identify financial integration and weak exogeneity in our monthly time series.

Our equilibrium is characterized by three cointegrating vectors, which, following Kasa (1992), suggests that the individual stock markets are fully and perfectly integrated. However, to improve the analysis, we consider the existence of structural breaks, applying the Bai–Perron test and then testing the FCVAR model in each of four regimes—regimes that correspond to the introduction of the Euro currency, the financial crisis, the end of the sovereign debt crisis and a final period that runs through November 2016. The FCVAR model indicates some significant differences

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in patterns of convergence throughout the original sample as a function of the regime studied. The results for the different regimes show that, for the most part, integration of the European markets has been complete but also that, during the sovereign debt crisis, full integration of these indices disappeared. The reason for this development is that the IBEX 35 index went out of long-run equilibrium, which could mean that this index was more sensitive during this quarrelsome period, while the other markets were more robust—i.e., that the IBEX 35 index is the weak link in the integration. We therefore wish to emphasize the case of the Italian market (FTSE MIB), which, like the others, suffered from a sovereign debt crisis but, in contrast to the others, remained in the long-run relationship. Once this turbulent period ended, full Euro financial integration resumed, as we see in the fourth regime, although interest rates spreads, notably those of Italy, started to increase again in the second half of 2016. Financial integration is attributable to technological advances during recent decades, which has reduced transaction costs and allowed for greater access to information, notably reducing differences between national and international financial transactions. It has thus contributed to more sustainable economic growth.

The findings of the paper have important implications for investors and policymakers. For investors, the high degree of integration implies a more attractive place for investment. However, this equilibrium also implies that portfolio diversification will be less effective. As stock market prices are interrelated, the possibility of strong impacts from external shocks is not reduced. In this line, cointegration is not the same as contagion. This is because cointegration may imply perfect spillover or, alternatively, no spillover at all if the variables are driven by a common third factor, which may be a global factor (Belke et al. 2017). For policy makers, market integration in the Eurozone has led to various debates. Market integration has increased competition and market efficiency and led to greater interdependence between the Eurozone markets; this may require increased supervision and securities market oversight, as Mylonidis and Kollias (2010) and Fratzscher (2002) find in their studies. Therefore, investors will prefer to invest in markets characterized by increasing growth, which will give them more investment options and risk diversification opportunities (e.g., buying stocks in two submarkets). There is thus potential gain through a focus on local rather than global factors. Future research into long-run relationships among the selected stock markets may focus on cycles to find possible synchronicity among markets. In addition, testing for breaks in the dynamics may be a new analytical approach to understanding the integration of markets. That is, future research could be oriented to the study of breaks in the dynamics of a Fractional Cointegration Approach, for instance, applying recursive AQ6 estimation or rolling cointegration.

Appendix

Original sample

See Tables 11 and 12.

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Table 11 Lag length selection

K	LR statistics	AIC	BIC
0	0.00	−3512.62	−3440.70
1	56.88	−3537.50	**−3410.78**
2	27.76	−3533.27	−3351.75
3	87.67	−3588.94	−3352.62
4	36.42	−3593.36	−3302.24
5	−2.01	−3559.35	−3213.43
6	108.55	−3635.90	−3235.18

The table shows lag length selection and bold indicates lag order selected. The sample size is 227

Table 12 Cointegration rank test

Rank	Log-likelihood	LR statistics	*P* value
0	1779.254	52.996	0.060
1	1788.489	34.525	0.033
2	1792.018	27.468	0.003
3	1805.231	1.042	0.307
4	1805.752	–	–

The table shows the rank test. Following Jones et al. (2014), the significance level is set to 10% for exclusion. The sample size is 227

Regime 1

See Table 13.

Table 13 Cointegration rank test

Rank	Log-likelihood	LR statistics	*P* value
0	294.552	56.201	0.000
1	307.954	29.397	0.001
2	317.988	9.330	0.053
3	321.685	1.934	0.164
4	322.652	–	–

The table shows the rank test. Following Jones et al. (2014), the significance level is set to 10% for exclusion. The sample size is 41

Regime 2

See Table 14.

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Table 14 Cointegration rank test

Rank	Log-likelihood	LR statistics	*P* value
0	583.557	84.570	0.000
1	598.455	54.774	0.000
2	617.983	15.718	0.003
3	625.788	0.109	0.741
4	625.842	–	–

The table shows the rank test. Following Jones et al. (2014), the significance level is set to 10% for exclusion. The sample size is 74

Regime 3

See Table 15.

Table 15 Cointegration rank test

Rank	Log-likelihood	LR statistics	*P* value
0	436.957	37.846	0.001
1	442.765	26.231	0.001
2	454.411	2.939	0.568
3	455.608	0.545	0.460
4	455.880	–	–

The table shows the rank test. Following Jones et al. (2014), the significance level is set to 10% for exclusion. The sample size is 58

Regime 4

See Table 16.

Table 16 Cointegration rank test

Rank	Log-likelihood	LR statistics	*P* value
0	442.787	51.266	0.000
1	444.708	47.425	0.000
2	462.616	11.608	0.020
3	467.517	1.806	0.178
4	468.420	–	–

The table shows the rank test. Following Jones et al. (2014), the significance level is set to 10% for exclusion. The sample size is 54

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